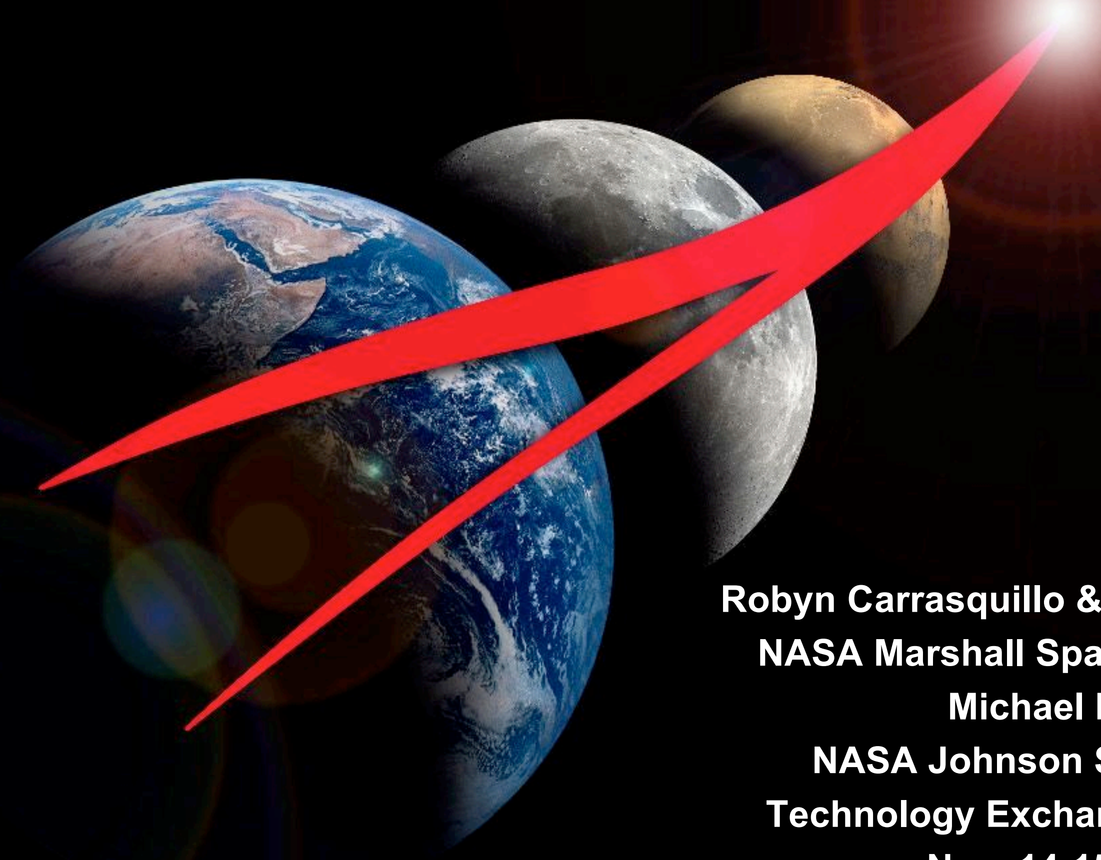
Life Support Technology Challenges for NASA's Constellation Program



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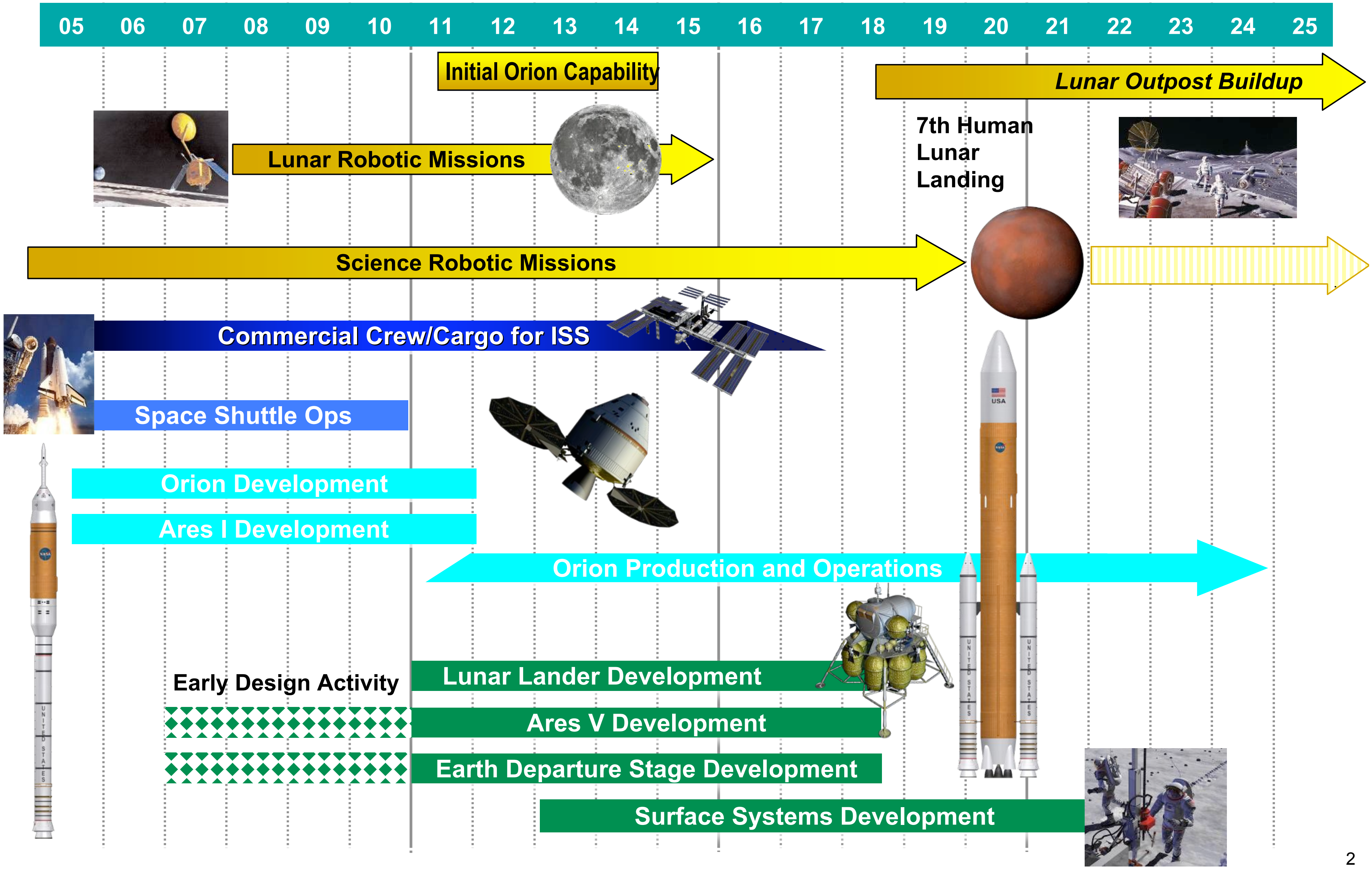
NASA's Exploration Roadmap



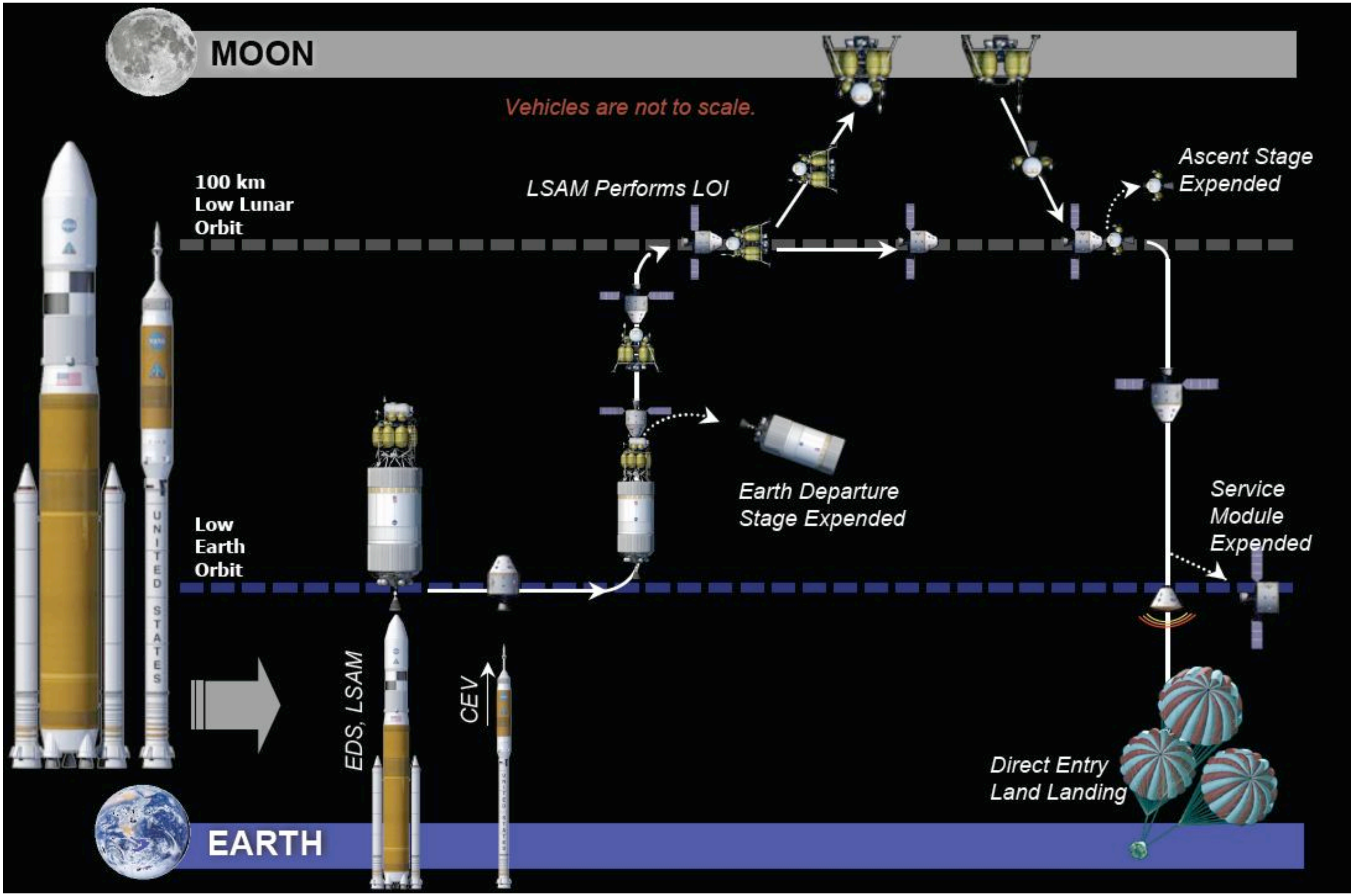
Overview of Mission Phases

- ISS crew/cargo transfer
- Initial Lunar
- Lunar Outpost
- Mars Transit
- Mars Outpost

ISS Mission

- Transport up to 6 crew members on Orion for crew rotation
- 210 day stay time
- Emergency lifeboat for entire ISS crew
- Deliver pressurized cargo for ISS resupply

Lunar Mission



Lunar Lander

- Transports 4 crew to and from the surface
  - Short duration sorties on the surface
  - Lunar outpost crew rotation
- Global access capability
- Anytime return to Earth
- Capability to deliver dedicated cargo
- Airlock for surface activities
- Descent stage:
  - Liquid oxygen / liquid hydrogen propulsion
- Ascent stage:
  - Storable Propellants

Lunar Outpost

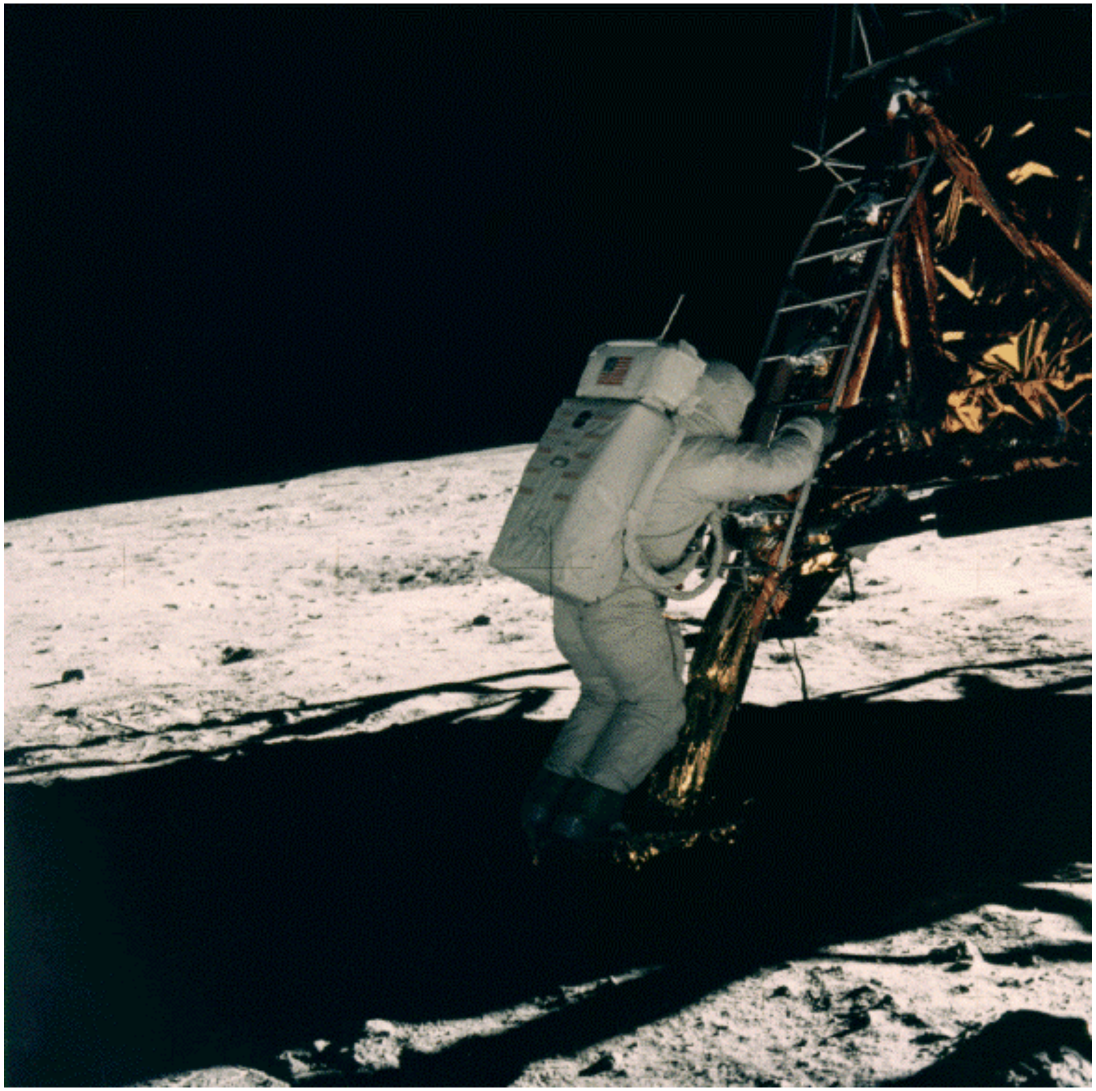
- Habitat supporting 4 crew
- Capability for daily EVA
- Use of ISRU
- Pressurized Rover

Unique New Requirements and Challenges

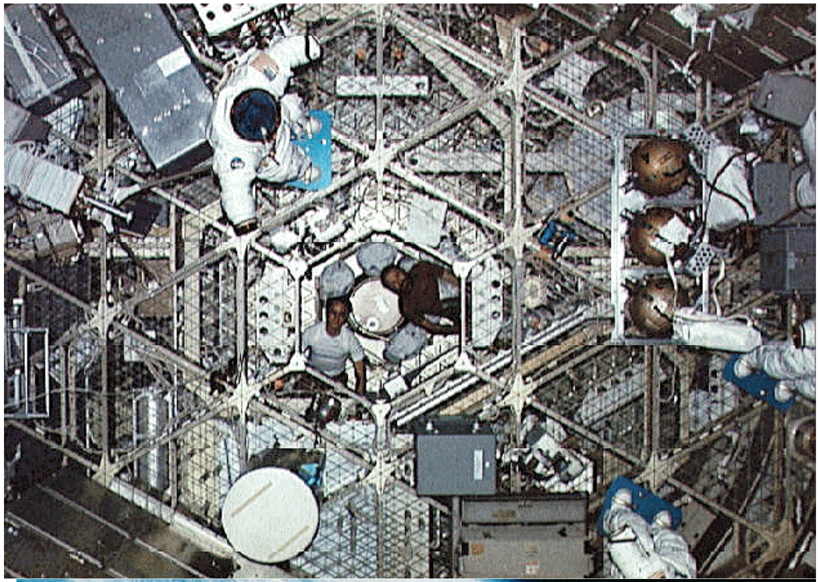
- **Carry up to 6 crew to the ISS**
  - Crew module must support 0-6 crew
- **Carry 4 crew to the moon**
  - Crew module must orbit moon unmanned for 6 months
- **Establish permanent Outpost**
  - Cargo lander to leave Outpost building blocks behind
- **Outpost will have limited resupply capability**
  - Life Support loops must approach closure to minimize resupply needs
  - ~6 months resupply interval
- **Frequent Outpost EVA's**
  - EVA life support with inherent losses of vented CO_2 and water
- **Pressurized rover for extended duration EVA's**
- **132 hour unpressurized survival in Command Module**
  - Life support system must support crew whether in open cabin or suits
- **Lunar dust environment**
- **Anywhere access on moon for lunar sorties**

Historical U.S. Life Support Systems

- **Apollo**
  - 3 crew
  - 6 m^3 habitable volume
  - 6-12 day mission lengths
  - Open loop expendable (LiOH) air revitalization system
  - Overboard urine vent
  - Rudimentary solid waste collection (bags)
  - 100% oxygen environment at 5 psia
  - Potable water from fuel cells
  - Suit loop for emergency depress survival



Historical U.S. Life Support Systems

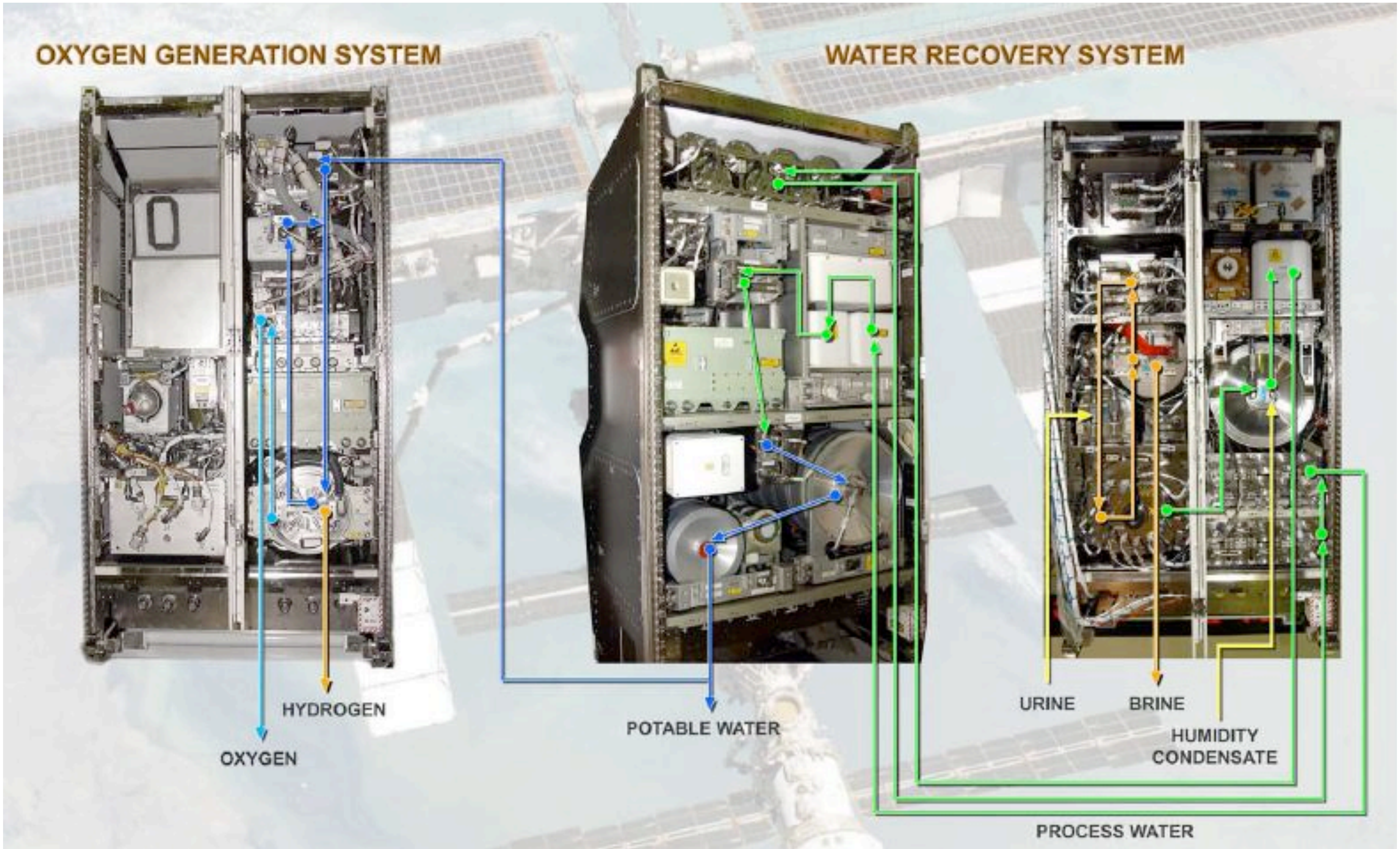


- **Skylab**
  - 3-person laboratory
  - 28-84 day missions
  - 361 m^3 total habitable volume
  - Mixed O_2/N_2 atmosphere at 5 psia; 72% O_2/28% N_2
  - 2-bed molecular sieve regenerable CO_2/humidity removal, desorbed to space. Activated charcoal for trace contaminant control during missions; venting of laboratory between missions avoided long-term contaminant buildup.
  - Condensing heat exchanger for further humidity control
  - Potable water launched with Orbital Workshop
  - Disposable bag waste collection

Historical U.S. Life Support Systems

- **International Space Station**
  - **3-person crew; to go to 6-crew with activation of Regenerative ECLSS**
  - **Regenerative zeolite CO_2 removal, vented overboard**
  - **Ambient pressure oxygen generation via water electrolysis**
  - **Scar for CO_2 reduction (Sabatier)**
  - **Expendable and catalytic oxidation trace contaminant control**
  - **Urine and humidity condensate water processing (2008)**
    - **Distillation, multifiltration, and catalytic oxidation**
    - **93% recovery of wastewater to potable quality**

ISS Regenerative ECLSS



Improvements Needed Over State of the Art Historical Systems – Short-Duration Vehicles

Atmosphere Revitalization

- **Regenerative open-loop atmosphere revitalization (CEV, lunar sortie lander, pressurized rover)**
  - CO_2 and humidity removal via vacuum swing adsorption eliminates need for condensing heat exchanger and expendable LiOH
  - Recovery of oxygen and water not critical for short-duration missions
  - Candidate technologies include amine and zeolite-based systems
- **Improved particulate filtration for lunar dust**
  - Filter particles to submicron levels
- **Emergency breathing mask which does not increase cabin %O_2 to unsafe levels.**
  - Looking at adapting commercial chemical mask.
- **Targeted trace contaminant adsorbents**
  - Ammonia from amine and suit loop contingency
  - Alcohols typically removed by condensing heat exchanger
- **Deployable post-fire cleanup device (aka "smoke eater")**

Improvements Needed Over State of the Art Historical Systems – Short-Duration Vehicles

Atmosphere Monitoring

- **Post-fire combustion products monitor**
- **Particulate monitor for lunar dust**
  - Monitor to 0.05 microns
- **Improved oxygen major constituent monitor**
  - Tighter oxygen control bands require +/- 0.05% accuracy
  - Longer calibration period
- **Fire detection that eliminates false positive alarms**

Improvements Needed Over State of the Art Historical Systems – Short-Duration Vehicles

Water Storage and Supply

- **Biocide**
  - Compatible with materials
  - Does not need to be removed for crew health
  - Stable for 6 month durations

Waste Collection

- **Improved urine pretreatment**
  - Low toxicity, non-corrosive
  - Simple introduction method
- **Solid waste containment that lends itself to transfer to Outpost for water recovery**
- **Simplified, no power, urine separator/vent that works with both genders**
  - Apollo “can” worked marginally well for males only.
  - Needed as backup if spin separator fails

Lunar Surface ECLSS Functions

Pressure Control Subsystem
- O_2 Supply
- N_2 Supply
- Positive Pressure Relief
- Intermodule Pressure Equalization
- Cabin Depress
- Cabin Pressure Monitoring

Fire Detection & Suppression Subsystem
- Fire Detection
- Fire Suppression

Emergency Equipment
- O_2 Masks
- Toxic Masks

Air Revitalization Subsystem
- CO_2 Removal
- CO_2 Reduction
- O_2 Generation
- Temperature & Humidity Control
- Trace Contaminant Control
  - regenerative
  - non-regenerative (for module ingress)
- Ventilation
  - intramodule
  - intermodule
- Airborne Particulate Control
- Atmosphere Composition Monitoring
  - ppO_2
  - pp CO_2
  - pp H_2O (v)
  - Trace Contaminant

Water Recovery & Mgmt Subsystem
- H_2O Recovery
  - Humidity Condensate
  - Waste Hygiene
  - Urine
- Brine Recovery
- Water Storage & Distribution
- Water Quality Monitoring

Waste Mgmt Subsystem
- Waste Collection & Drying
- Trash Compaction & Drying

Improvements Needed Over State of the Art Historical Systems – Long-Duration Missions

Atmosphere Revitalization

- **Atmosphere loop closure**
  - Improved CO2 removal – more robust, lower power, integration with CO2 reduction
    - Structured sorbents to preclude dust generation
    - Water separation which minimizes power/heat for regeneration
    - Mechanical or chemical adsorption-based CO2 compression and storage
  - CO2 reduction
    - Sabatier only (50% oxygen recovery from CO2)
    - Complete oxygen recovery from CO2
      - Challenge is to minimize resupply of catalyst/expendables for this to trade positively over bringing additional water
      - Sabatier plus hydrogen recovery from methane
      - Bosch

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Improvements Needed Over State of the Art Historical Systems – Long-Duration Missions

Atmosphere Revitalization, cont.

- **High pressure oxygen generation for EVA and storage**
  - Possible synergy with Power regenerative fuel cells and ISRU
- **Potential need for improved hydrogen sensor**
  - Based on ultimate design of HPOGA and other hydrogen-containing systems (like Sabatier, fuel cells, etc).
- **Improved particulate filtration for lunar dust**
  - Specific application for outpost/airlock
  - Methods to prevent dust from entering airlock
  - Methods to remove dust from atmosphere
  - Robust seals, connectors
- **Improved Trace Contaminant catalysts, sorbents**
  - Reduce expendables
  - Lower catalytic oxidation temperature
  - Possible photocatalytic filtration of entire air stream to reduce contaminant load of condensate (currently performing trades)
  - Possible incorporation into integrated CO2 removal/reduction system

Improvements Needed Over State of the Art Historical Systems – Long-Duration Missions

Atmosphere Monitoring

- **Post-fire cleanup monitor (combustion products) – same as short-duration mission need**
- **Particulate monitor for lunar dust – same as short-duration mission need**
- **Trace Contaminant Monitor**
  - Long-duration contaminant buildup concern, and inability to bring back samples for analysis
- **Microbial monitor**

Improvements Needed Over State of the Art Historical Systems – Long-Duration Missions

Water Processing

- **Improved water recovery**
  - >95% water recovery from wastewater (primary processor)
  - ~100% water recovery from brine
  - Decreased expendables – filters, absorption media
    - Current ISS water recovery system uses 8 lb resupply/100 lb water recovered including maintainable items (2.7 lb expendables/100 lb water recovered)
  - Consider use of partial gravity to simplify planetary base system
    - Potential use of modular components that could be added to partial-g system to function in micro-g
  - Improved urine pretreat (from short-duration vehicle list) is key to this effort as well.
- **In-line TOC monitor**
  - For improved long-term process control and monitoring of water system
- **Biocide monitor**

Improvements Needed Over State of the Art Historical Systems – Long-Duration Missions

Waste Storage/Processing

- **Recovery of water from solid waste (metabolic and trash)**
  - Tentative target is 50% recovery of water from solid waste
  - Methods to avoid physical transfer of waste from collection container to processor
    - Possibly retrieve containers from Lander to recover resources
- **Stabilization and long-term storage of solid waste**
  - Could include waste compaction and drying

Improvements Needed Over State of the Art Historical Systems – Long-Duration Missions

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Habitability Functions

- **Laundry**
  - Preliminary trades look favorable
  - Includes need for soap development that is compatible with water processor and crewmembers
  - Lightweight clothing system must also be defined
- **Vacuum cleaner (for lunar dust) and other crew equipment needs**
- **Low energy lighting, crew quarters and galley equipment**